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THE IMPACT OF ENGINEERING ON HUMAN WELFARE IN THE AGE OF SPACE EXPLORATION

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It is a privilege and pleasure to join you in this day of tribute to the men who follow the profession of engineering. These are the men who play a key role in the continuing transformation of our physical environment. We have only to look around us to find visible evidence of the handiwork of the engineer. The building in which we meet, the electric lights overhead, the public address system, the air we breathe, the food we eat -- all are evidence of the men among us who apply the material resources and the energy sources of nature to the purposes of man.

Many of you present belong to this great profession. It may seem somewhat self-serving that you should be blowing your own horn today, with some implication that the whole job of recreating man's physical environment into comfortable, convenient, and luxurious living has been accomplished by engineers alone. We make no such claim. Our complex civilization is founded on the work of many; we live in an age of increasing specialization. All are interdependent. The farmer, the merchant, the banker, the doctor, the lawyer, the citizen of whatever group are all indebted to the engineer and dependent on his work. The engineer in turn is dependent on all of them. But I think that there are few groups whose work is so much taken for granted and so little understood by the public and whose very name is rarely associated with the great accomplishments of the profession. I noted just recently a book on the history of Western Civilizations in which the words engineer and engineering do not appear.

Some of you present are not engineers but belong to influential groups of citizens of this and other cities. We seek your collaboration in promoting a wider understanding of the contributions of engineering to our way of life, and of the aims and objectives of the engineering profession. A great engineer, Glenn Warren, has explained the professional character of engineering -- that engineers have by experience and study accumulated a special body of knowledge regarding natural resources; that, engineers feel a compulsion to use this knowledge in the public interest, to add to the store of engineering knowledge by their own efforts, and to teach this new knowledge to their contemporaries and to future generations.

My remarks today are addressed in the main to all of you as members of the wider community. The Age of Space Exploration has some special implications for engineers which I will touch on briefly at the end.

In an article in Mechanical Engineering in January 1926 Dr. W. F. Durand, until his death the unquestioned Dean of the engineering profession, traces the genealogy of the engineer of today to that caveman in France some twenty-five thousand years ago who practiced the art of fashioning flint arrow and spearheads perfect in form, proportion, and finish. In his work there were the beginnings of those functions which we now designate as those of the industrialist, inventor, and engineer. Somewhat later were those who developed the art of weaving, first expressed in basketry, then the embryonic ceramic engineer who developed the first clay pottery. There followed, as told by Durand, a succession -- the military engineers who produced the first bow and arrow and the first sling, the marine engineer of 15,000 years ago who produced the first dugout, the bridge builders, the metallurgical engineer Tubal Cain, and so forth. Today I think we would regard these ancestors of modern engineers as artisans, although their purpose and role in society were nearly identical with those of engineers today.

It is customary to date the foundations of our modern mechanical civilization from the invention of the spinning "jenny" by James Hargreaves in 1767. The most important single invention of the Industrial Revolution was James Watt's steam engine first patented in 1769. Prior to this time the word engineering referred to the operations of those who constructed weapons of war and fortifications, bridges, and other works for military use. But with the Industrial Revolution there began to arise a new class of engineers who concerned themselves with construction, some such as roads of the same character as those undertaken by military engineers. However the work was not military in purpose and was not carried out by soldiers; hence these men by way of distinction came to be known as civil engineers. Thus civil engineering is the mother of many of the present specialized branches of engineering.

The first organized body of engineers was the Institution of Civil Engineers established in London in 1818. Civil engineering was described as the "art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters, and lighthouses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns."

Gradually specialization set in. Perhaps the first branch to be recognized as separate was mechanical engineering, soon followed by mining engineering. The number of special branches is now very great, including electrical, aeronautical, metallurgical, marine, chemical, illuminating, automotive, highway, structural, agricultural, sanitary, radio, electronic, etc., and now aero-space or astronautical. Perhaps the variety and number of prefatory adjectives has obscured the public image of engineering as a single profession.

There have been many modern capsule descriptions of the work of an engineer by members of the profession. Gano Dunn defined engineering as the art of the economic application of science to the purpose of man. M. P. O'Brien stated that engineering was the art and science of converting design concepts into working hardware which can be manufactured and sold at a profit. J. H. Keenan states the purpose of engineering as the use of the resources of nature for social ends, to bridge the gap between the known and the desired. There are undoubtedly many others in the literature of other branches of engineering than those given here by noted mechanical engineers.

You will note the appearance of the word science in some of these definitions, a word that I have not previously mentioned. Keenan gives a contrasting definition of the purpose of science as to know and understand nature, to bridge the gap between the known and unknown. In general the press, both newspaper and magazine writers, use the term science as a generic term covering all activities leading to the creation and construction of a given material object or device. This has led to much confusion and to many attempts to set the record straight. Dr. John Hrones, Vice-President of Case Institute of Technology for Academic Affairs comments as follows, "The great engineering achievements of the past decade are always attributed to the scientists and the role of the engineer is never delineated. The development of the atomic bomb, the development of nuclear power, the development of the atomic submarines, and the development of satellites and space probes are always spoken of as scientific achievements where, in reality, they are major engineering accomplishments. True enough," he continues, "science unlocked important secrets of nature to make them possible, but yet, the real achievement has been an engineering one--that of bringing into being a complicated system which nobody previously had believed could be accomplished. There are so many of these amazingly fine engineering achievements for which the engineer has received no credit because the term science was used to cover the total development."

In truth the work of the engineer is closely related to that of scientist, manager, industrialist, economist, manufacturer as evidenced by the words science, manufacture, profit, social in the several definitions. The modern engineer must be in part engineering scientist, industrial leader, cost analyst, and public servant. In seeking recognition of his primary role of bridging the gap between the known and the desired, as Keenan put it, he demands no less recognition than those whose primary mission is science, economics, or other field.

Our topic is the impact of engineering on human welfare. Whether the desires of man and nations lead to human welfare depends neither on the specialized techniques of engineering or science nor on the material environment which they have so drastically changed but on the spiritual environment. The engineering profession has furnished many of our finest national leaders in undertakings to alleviate human suffering and to promote the intellectual and spiritual life of man. Their purely engineering accomplishments have provided a material environment which men can use to benefit the human race. Transportation and communication make possible the neutralization of physical barriers between men of different races. Manufacturing techniques make available the luxuries of life to multitudes, provide in power the equivalent of many slaves to carry out arduous tasks. If material achievements are not used for human benefit, the fault is not alone that of the engineer. I believe that the testimony of history and of multitudes of men and women is that the net results of their labor have provided immeasurable benefits to the human race.

On October 4, 1957 man entered the Age of the Exploration of Space by direct methods, first with instruments, some with man. How does this modify our past experience? What is now the role of the engineer? What adjustments in outlook and training are necessary? How is human welfare involved in these activities?

Let us look briefly at the current activities in space exploration. The most visible and spectacular aspect is the succession of launchings of space vehicles to carry out desired missions. However the larger part of the total activity, like the submerged portion of an iceberg, is hidden from public view. Each mission requires the availability of a suitable launch vehicle, and a spacecraft provided with the required instruments and equipment. Each mission requires the operation of suitable ground facilities to receive and record telemetry, to track the spacecraft for determining its position continuously, to photograph its track, send command signals, or whatever else may be required by the mission. These developments must be carried out in proper time phase to be completed at the mission date. In addition to these developments, a broad foundation of advanced research and technology carried out in laboratory facilities on the ground is prerequisite to leadership in space exploration.

The space flight missions of our own national space exploration program fall into three categories. The first includes those missions directly concerned with the travel of man himself into space, extending in the foreseeable future throughout the solar system. The second comprises the application of earth satellites to human benefit. The third is composed of those missions whose object is the scientific study of the space environment. Together these categories form a single broad integrated program of space exploration and no category can be neglected without detriment to the others. Thus it is obvious that the results of the scientific missions are essential to the design of space vehicles. The engineer needs quantitative detailed information on the Van Allen radiation belt including variations in intensity with time. He also needs statistical data on the distribution of meteorites of various sizes. Similarly the accomplishment of various steps in manned flight contributes to the scientific knowledge of space and provides means for making more complex scientific measurements by human observers. Project Mercury, the first step by this nation in the travel of man in space at satellite speeds and beyond, illustrates what I mean. A DX priority -- the highest national priority, has been assigned the project, and if everything goes well, a man may be put into a ballistic trajectory during this calendar year. Soon thereafter we will begin to gain direct experience in the orbital flight of man.

Our program looks forward to a continually increasing capability and accumulation of experience. Much of our advanced research and technology is planned to attack the problems to be encountered in the travel of man to the moon and his safe return to earth. As we advance toward this goal, we must achieve such intermediate goals as a manned space station in orbit about the earth and the flight of man to orbit the moon and return safely to earth. We must develop spacecraft capable of reentering the earth's atmosphere not only from earth satellite speeds without excessive heating or deceleration, but also from the much higher speeds involved in return from the moon. We know already that there is a difficult guidance problem connected with the safe return through the atmosphere.

The program includes missions leading to the applications of earth satellites for peaceful purposes to promote human welfare. These applications have been of great interest to men of all nations. The development of meteorological satellites is one of the important goals of the national program. Still in the earliest research and development stage as regards the instrumentation, the results already obtained open new vistas to the forecaster and research scientist alike. A second application of special benefit to the Western world is that to the task of long-distance communication.

The third category of missions includes those used for the unmanned exploration of space. Satellites and space probes can carry our measuring instruments far into space, in time to the far reaches of the solar system. They do precede man and explore the way for him, but more important they extend the body of scientific knowledge about the earth, its atmosphere, ionosphere, and other aspects of nearby space, about the moon and planets, and about our entire universe. Although we speak of this program as a space science program, it in fact includes a multiplicity of programs in gravitational, electrical, and magnetic fields, cosmic rays, electrified particles, radiations of all wave lengths, in fact all branches of physics and chemistry extended into outer space. The results promise to benefit our activities on earth as much as our activities in space, and in a sense this category of missions also represents the application of satellites and space probes for peaceful purposes to promote human welfare.

The accomplishments of the national space exploration program to date have been substantial. Experience in its conduct has made us more acutely aware of the unknown factors in the conduct of research and development on the previously unexplored frontiers of space. The course ahead for several years is well established and we have made plans for a decade ahead in the light of our present knowledge. We expect to revise these plans from time to time in the light of the experience gained.

In recent testimony before the Congress, NASA outlined the general features of this plan. It anticipates a progressive growth in our capability to explore space with spacecraft of increasing size, versatility, and technical complexity. In the 1963-1967 time period, our increasing capability will be primarily attributable to the use of the Saturn first stage and successively improved upper stages based on employment of liquid hydrogen and liquid oxygen. Our total capabilities are being developed to the point where it is anticipated that a program of more than two launches per month will be conducted for major application and exploration missions in space.

Some of the major milestones in the ten-year plan are as follows. The beginning of tests of several vehicle development programs as well as the first major orbital experiments in both meteorology and communications will take place in the current year. There is also scheduled, as previously mentioned, the first suborbital flight of an astronaut, boosted more than 100 miles into space with a Redstone vehicle. In the calendar year 1961 we are working toward the launching of a sophisticated lunar impact vehicle and a further step forward in our vehicle development program with the initiation of flight tests on the Centaur. Centaur uses an Atlas first stage, and a new second stage with a liquid hydrogen and liquid oxygen engine, the first to use these fuels.

Assuming continued success in the schedule of tests for Project Mercury, the first orbital flight of a manned space vehicle will occur in calendar year 1961. From there we proceed through the ten-year period with a comprehensive program of exploration of the moon and near planets and developing the Saturn launch vehicle to provide the necessary information and capability for the beginning of manned circumlunar flight in the latter part of the decade. As we now analyze the requirements for launch vehicles and new knowledge yet to be gained, it appears that a manned landing on the moon will fall in the time period beyond 1970.

As we move forward in space exploration and the development of space technology, we are reminded of the early days of aeronautics. In that day too, men tried to foresee the impact of human flight on human welfare, but imagination and vision were limited. We can see some direct material benefits of such satellite applications as to communications and meteorology. We understand the utility of earth satellites for such military tasks as reconnaissance and early warning and we believe that the strengthening of national defense is a contribution to human welfare. We have the feeling that the more significant benefits are presently unknown.

We see now many indirect benefits arising from the development of new scientific knowledge and new engineering advances which will find application in many other fields. For space exploration does require the most advanced engineering and technological developments of our time. The need is to produce vehicles which travel at extreme speeds, withstand the extreme cold of outer space and the extreme heating of atmospheric reentry, the extreme vacuum of space, the impact of meteorites, the blaze of radiant energy of all wave lengths, the shower of charged particles of widely varying energies. Equipment is demanded which will function unattended for years. Communication with the vehicle at distances of millions of miles stretches the engineering art. Guidance systems of novel design and high accuracy present great challenges. Complex light weight computing devices are required. Because of these requirements space accomplishment has become in the minds of many a symbol of a nation's stature in all of science and engineering. It is thus an element in the determination of national prestige, and it is abundantly clear that the desire of other nations to follow leadership has incalculable effects on human welfare.

The age of space exploration has many implications for engineering and engineers. It brings increased pressures to accelerate the tempo of changes in engineering education and practice which began during the last war. There then arose areas of development in fields such as radar and nuclear energy, which were inherently engineering developments. However, there were few engineers available who knew enough about the scientific advances to exploit them and in fact engineering developments in hitherto unexplored fields were also necessary. To meet the needs science and engineering became closely intertwined and a new breed of engineers appeared on the scene, some from a background of physics or chemistry who absorbed engineering knowledge and techniques, some from a background of engineering who became knowledgable of nuclear physics and chemistry. It turned out that the best qualification that this new nuclear engineer could possess was a thorough knowledge of the basic principles of mathematics, physics, and technology. An engineer who understood the basic principles of heat transfer could apply them to many new situations in new technologies, for example to the cooling of a radar transmitter tube or of a reactor fuel element. An engineer with the classical training which specialized in the engineering problems of a single industry had great difficulty with the more basic approach. Thus less specialization and a greater integration of basic scientific principles underlying all engineering application became the essentials for survival in a rapidly changing science and technology.

While I have related the principal cause of this change in engineering practice to nuclear engineering, the roots of the change lie also in developments in aeronautical and guided missile engineering, at least in the later stages. Even prior to the last war the design of aircraft had expanded from the solo effort of the inventor to a group effort of a large design team, consisting of many specialists. Even so, the design problem could be readily broken down into aerodynamic, structural, electrical, hydraulic and similar smaller areas, whose interactions were mainly the dimensional ones of available space and proper mating of parts.

As speeds increased, the aerodynamicist began to complain of the many crude excrescences demanded by the electronics group for radio and radar antennae. As structural design was refined, the mutual effects of aerodynamic loads on structural deflection and of structural deflection on aerodynamic loads introduced problems of flutter. In short, the mutual interactions became very great and new methods of overall system analysis and functional coordination became essential. The guided missile problems accentuated this development of large engineering teams of more kinds of specialists with knowledge of more scientific fields. Space exploration continues this trend still further. Every old branch of knowledge and some new ones need to be represented.

Space exploration, like the nuclear energy field before it, now requires the close collaboration of scientists and engineers. However the situation is in a sense reversed. In the nuclear field the scientific developments come first. In space exploration, extensive engineering developments are necessary to enable scientists to make measurements in space. More than 85% of our effort in NASA is devoted to engineering problems connected with the design, construction, and operation of launching vehicles, the payloads, the tracking stations and the acquisition and reduction of data. This engineering work is dependent on the work of many other scientists but it is in turn the prerequisite to the work of the experimental scientist seeking new knowledge of the space environment, the earth, moon, and planets and the universe as a whole.

In addition to purely technical and management aspects of engineering practice, engineering at its highest involves a collaboration effort with businessmen, bankers, and public officials to assess worth while social objectives and to judge the technical and economic feasibility of projects designed to accomplish these objectives. As our society becomes more complex and science and engineering become cornerstones of national and international policy, we need men of broad experience to synthesize the contributions of the many professions involved, to integrate and amalgamate the available knowledge and thinking into the great enterprises of mankind. In the Age of Space Exploration it will be increasingly important that many of these national leaders rise from the ranks of science and engineering.

No enterprise has so stirred human imagination as the reach of man toward the exploration of space. New worlds to explore. New distances to travel, 3680 million miles to Pluto, the outermost planet of our solar system, 8 years' journey at 50,000 miles per hour, when we attain such a capability. Innumerable problems ahead. New knowledge needed in almost every branch of science and technology from magneto fluid dynamics to cosmology, from materials to biology and psychology. A tremendous challenge to engineers to make the visions come true, to reduce design concepts to hardware "with minimal cost and waste and the maximal useful results." Thus a new opportunity presents itself in the Age of Space Exploration for engineers to continue contributing to human welfare.